RESTRICTED CIRCULATION

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Meteorological aspects of odours spreading downwind from spread slurry

by N.Thompson

1. Introduction One of the difficulties in assessing how objectionable the odours are likely to be at various distances downwind from spread slurry is in the estimation of the actual source strength of the odours. The slurry surface will become modified by evaporation and by the action of sunshine, and the odour source strength will decrease as a crust builds up. The present note assumes that the source strength and its variations with time are known, and calculates how the odour concentration varies with distances from the source, and with meteorological conditions.

2. Assumptions The crosswind width of the area source of slurry odour is assumed to be large enough for edge effects (i.e. the reduction in odour strength by lateral diffusion) to be negligible. It is also assumed that the source strength is clearly defined (§ 1). Variations of wind speed with height are neglected but this is not a very restrictive condition. The speeds which will be referred to are roughly those at 2 m height: to obtain them from 10 m speeds in the cases considered below, multiply the latter by respectively 0.85, 0.75 and 0.6 for stability categories B, D and F (§ 4).

3. Definitions

Q	=	source strength per unit area (in units s^{-1})
X	=	distance downwind from downwind edge of source area
x	=	the distance upwind from this edge of a crosswind element of source of unit alongwind width
u	=	wind speed
A-F	=	Pasquill stability categories
z	=	height above ground
$\chi(X+x)$	=	concentration at height z , distance $X+x$, produced by release from a single source element (units m^{-3})
L	=	alongwind length of spread area
$\Sigma\chi$	=	sum of concentration of aerosol from all the source elements

4. Method The approach is based on that of Pasquill (1961, 1974). He classifies the "diffusive" power of atmospheric turbulence into six broad categories (Table 1) related to simply observed or measured quantities.

Table 1 Pasquill's stability categories

10 m wind (ms^{-1})	Insolation			Night	
	Strong	Moderate	Slight	≥ 4/8 low cloud	< 4/8 cloud
< 2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
> 6	C	D	D	D	D

Strong insolation ≡ sunny midday in summer
Slight insolation ≡ sunny midday in winter
Night ≡ 1 hr before sunset to 1 hr after dawn
Use Category D in overcast conditions and for the hour proceeding or following night as defined above

Pasquill gives graphs for each category showing the standard deviation (σ_z) of the distribution of aerosol in the vertical (taken about the ground as origin) from a ground level source, for a range of distances of travel. These results can be applied directly to the present case by dividing the source area into crosswind strips of unit downwind length. Then the concentration at height z produced by a strip source of aerosol located a distance x upwind of the source edge is

$$\chi(X+x,z) = A Q f(X+x,z) \qquad (1)$$

$$\Sigma\chi = A Q \int_0^L f(X+x,z)\,dx \qquad (2)$$

where A is a function of wind speed only. The assumption is made that the aerosol from the strip becomes distributed normally in the vertical, and if deposition of aerosol is negligible then the following expression may be derived

$$\chi(X+x,z) = \frac{2Q}{(2\pi)^{1/2} u \sigma_z} \exp(-z^2/2\sigma_z^2) \qquad (3)$$

: the problem then reduces to specifying σ_z , preferably in a form which allows Eq.(3) to be readily integrated.

Pasquill gives empirical data for σ_z which may be represented analytically with sufficient accuracy by

$$\sigma_z = a(x')^s \qquad (4)$$

where $x' = X + x$, and a and s are functions of stability and surface roughness. Equation (2) then becomes

$$\Sigma\chi(x',z) = B\int_0^L (x')^{-s} \exp(-bz^2/(x')^{2s})\,dx' \qquad (5)$$

where B and b are independent of x . The integral is inconvenient and a solution by summation is used.

A wind speed of $3ms^{-1}$ was selected (concentrations at other speeds but the same stability category are obtained by multiplying the results by $3/u$). Roughness length was assumed to be 0.01 m, which is appropriate to fairly short (≃ 0.1 m) tussochy grass, tufty stubble or lumpy ploughed land (which are presumed to be representative of the types of surface on which slurry will be spread). The

calculations were performed for stability categories B (fairly unstable), D (near-neutral) and F (fairly stable). In these conditions Pasquill's data give the following values for σ_z (in metres):

$$\text{(B)} \quad \sigma_z = 0.12\,(x')^{0.89}$$

$$\text{(D)} \quad \sigma_z = 0.097\,(x')^{0.81} \qquad (6)$$

$$\text{(F)} \quad \sigma_z = 0.055\,(x')^{0.72}$$

The height z is assumed to be 1.5 m, which is approximately the human head height.

5. Results Calculations were made for slurry-covered fields with alongwind lengths of 50, 100, 200 and 500 m, at sampling positions up to 1 km downwind of the fields. Results are given in Tables 2 and 3 as units per m^3 for odour source strengths of 1 unit $m^{-2}s^{-1}$. Some of the results require discussion. For example the low concentrations in class F conditions when sampled close to small fields are the consequence of the low rate of vertical diffusion in these stable conditions: the aerosol has barely diffused to the height of 1.5 m even after some tens of metres travel. For this reason the maximum concentrations in F conditions are sampled a short distance downwind of the field and fall off rather slowly with increasing distance. The main point which emerges is how much more objectionable the odours are likely to be in evening or nocturnal conditions than during the daytime, for the same source strength. For example in the case of a 200 m long field covered in slurry with the receptor at least 200 m downwind of the field the concentrations are about 6 times larger in the nighttime case, and the factor may double again when account is taken of the lighter winds experienced usually at night.

However, reliable estimates of the relative odours in the day and night-time cases must await quantitative data on source strengths of the odours for slurries spread and producing aerosols in a range of meteorological conditions (covering high and low temperatures, humidities, wind speeds and net radiation, and in precipitating and non-precipitating cases).

Edge effects have been ignored up to this point of the analysis. This approximation will be a good one at a given distance downwind when the receptor is placed downwind of the field centre, and the standard deviation at receptor distance of the lateral distribution of aerosol produced by a point source in the field is about one third of the field width. However the errors will not be large on the centre-line even when the field width is only about two standard deviations. One may use this latter criteria with Pasquill's data for lateral diffusion to calculate the maximum distance downwind of a field of restricted width where the results in Table 3 are still valid (on the downwind line passing through the field centre). The results in Table 4 have been obtained assuming that the average (point) source distance is L/2 upwind from the downwind edge of the field. In conditions D and particularly F the plumes from point sources are narrow and so the receptor has to be carefully positioned (i.e. wind direction specified to 1 or 2 degrees) if the field is not very wide in order to sample the concentrations given in Table 3

Any comments or suggestions on this paper should be referred to the author

Meteorological Office, Met O 8a
London Road
Bracknell
Berkshire

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Table 2 Normalised aerosol concentrations at a height of 1.5 m produced by wide crosswind sources placed at various distances upwind of receptor (source strength is 1 unit $m^{-2}s^{-1}$). Results have been normalised by the alongwind length of strip and refer therefore to equivalent source lengths of 1 m

Distances of source strip boundaries from receptor (m)	Concentration at receptor from equivalent 1 m long strip (units m^{-3})		
	B	D	F
0-10	.021	.0053	0
10-20	.101	.067	.0013
20-30	.098	.104	.015
30-40	.082	.104	.040
40-50	.077	.096	.067
50-60	.064	.088	.085
60-70	.053	.082	.096
70-80	.048	.077	.104
80-90	.043	.071	.109
90-100	.040	.065	.109
100-120	.035	.059	.106
120-140	.031	.052	.103
140-180	.027	.046	.098
160-180	.024	.042	.095
180-200	.021	.038	.093
200-250	.017	.032	.085
250-300	.015	.027	.077
300-400	.012	.023	.069
400-500	.010	.020	.056
500-600	.0082	.017	.048
600-800	.0067	.014	.043
800-1000	.0053	.011	.037
1000-1500	.0041	.0090	.030
1500-2000	.0032	.0069	.024

Note: The Table may be used to estimate the concentration at the receptor for a given strip width and value of $\times$. Thus for $\llcorner$ = 20 and $\times$ = 10 the concentration is obtained by multiplying results in the second and third rows in the Table by 10 (the strip width) and adding them, giving a receptor concentration in B stability of 1.01+0.98=1.99 units m^{-3}.

Table 3 Aerosol concentrations (units m^{-3}) at a height of 1.5 m at different distances downwind of fields

Distance of receptor from downwind edge of field (m)	Aerosol concentration at 1.5 m height											
	L = 50 m			L = 100			L = 200			L = 500		
	B	D	F	B	D	F	B	D	F	B	D	F
0	3.8	3.7	1.2	6.3	7.6	6.3	9.0	12.3	16.2	12.4	19.6	36.8
20	3.8	4.7	3.0	5.7	8.0	8.4	8.8	12.2	17.9	12.3	19.6	38.5
50	2.5	3.8	5.0	4.0	6.5	10.2	5.9	10.1	19.0	9.3	16.8	37.7
100	1.5	2.7	5.2	2.7	5.0	10.0	4.3	7.9	18.1	7.3	14.0	35.4
200	0.9	1.6	4.3	1.7	2.9	8.1	2.9	5.3	15.0	5.5	10.4	29.7
500	0.5	0.9	2.7	0.8	1.7	5.2	1.5	3.2	10.0	3.2	6.9	21.7
1000	0.24	0.5	1.6	0.5	1.0	3.2	0.9	1.9	6.3	2.1	4.6	15.2

Note: source strength is 1 unit $m^{-3}s^{-1}$

Table 4 Approximate values of downwind distance (χ) up to which the results of Table 2 are valid for fields of finite width

Field width (m)	in metres											
	L = 50 m			L = 100			L = 200			L = 500		
	B	D	F	B	D	F	B	D	F	B	D	F
50	110	280	~600	90	250	550	-	200	500	-	-	~350
100	250	~600	>1000	220	~550	>1000	180	~500	>1000	-	~350	~1000
200	~500	>1000	>1000	~500	>1000	>1000	~400	>1000	>1000	~300	~1000	>1000
500	~1000	>1000	>1000	~1000	>1000	>1000	~1000	>1000	>1000	~850	>1000	>1000

Note: dashes indicate that alongwind length of field is sufficiently large in comparison with calculated value for χ for it to be impossible to give a reliable mean source distance - the calculated value for χ (small or negative in these cases) is not listed therefore.